Claims

1. A method for producing three-dimensional information of an object (4) in medical X-ray imaging, **characterized in that**
- the object is modelled mathematically independently of X-ray imaging,
- the object is X-radiated from at least two different directions and the said X-radiation is detected to form projection data of the object (4),
- and said projection data and said mathematical modelling of the object are utilized in Bayesian inversion based on Bayes' formula

$$p(x\,|\,m) = \frac{p_{pr}(x)p(m\,|\,x)}{p(m)}$$

to produce three-dimensional information of the object, the prior distribution $p_{pr}(x)$ representing mathematical modelling of the object, x representing the object image vector, which comprises values of the X-ray attenuation coefficient inside the object, m representing projection data, the likelihood distribution $p(m|x)$ representing the X-radiation attenuation model between the object image vector x and projection data m, p(m) being a normalization constant and the posteriori distribution $p(x|m)$ representing the three-dimensional information of the object (4).

2. A method according to claim 1, **characterized in that** the three-dimensional information of the object (4) is one or more two-dimensional images representing X-ray attenuation coefficient along slices through the object.

3. A method according to claim 1, **characterized in that** the three-dimensional information of the object (4) is a three-dimensional voxel representation of the X-ray attenuation in the object.

4. A method according to claim 1, **characterized in that** the measurement model is m = Ax+e, where matrix A contains the lengths of the path of the

X-ray inside each voxel and the noise e is independent of object image vector x leading to the likelihood distribution

$$p(m \mid x) = p_{noise}(m - Ax).$$

5. A method according to claim 1, **characterized in that** the said mathematical modelling comprises that X-radiation attenuates when passing the object (4), which means that every image voxel is nonnegative.

6. A method according to claim 1, **characterized in that** mathematical modelling is expressed by the formula:

$$p_{pr}(x) = \exp(-\alpha \sum_N U_N(x))$$

where the sum is taken over a collection of 3D neighbourhoods N and the value $U_N(x)$ depends only on the values of voxels belonging to the neighborhood N, and α is a positive regularization parameter used to tune the width of the prior distribution.

7. A method according to claim 1, **characterized in that** the 3D tomographic problem is divided into a stack of 2D tomographic problems and on every such 2D problem, the mathematical modelling is expressed by the formula:

$$p_{pr}(x) = \exp(-\alpha \sum_N U_N(x))$$

where the sum is taken over a collection of 2D neighbourhoods N and the value $U_N(x)$ depends only on the values of pixels belonging to the neighborhood N, and α is a positive regularization parameter used to tune the width of the prior distribution, and the 2D tomographic problems are related to each other by the formula

$$pr3D(x(j)) = \exp(-\gamma \sum\sum | x(j)[k,q] - x(j-1)[k,q] |),$$

where the sums are taken over all pixels (k=1,...,K, q=1,...,Q) and $\gamma > 0$ is another regularization parameter.

8. A method according to claim 7, **characterized in that** the neighborhoods consist of two adjacent pixels and U calculates a power of the absolute value of the difference, leading to the formula

$$p_{pr}(x^{(j)}) = \exp\Big(-\alpha\big(\sum_{k=1}^{K-1}\sum_{q=1}^{Q}|x^{(j)}[k,q]-x^{(j)}[k+1,q]|^s + \sum_{k=1}^{K}\sum_{q=1}^{Q-1}|x^{(j)}[k,q]-x^{(j)}[k,q+1]|^s\big)\Big)$$

where s is a positive real number.

9. A method according to claim 8, **characterized in that** s=1 corresponding to total variation (TV) prior describing objects (4) consisting of different regions with well-defined boundaries.

10. A method according to claim 1, **characterized in that** mathematical modelling is qualitative structural information of the target where the structural information is encoded in prior distributions that are concentrated around object image vectors x that correspond to the physiological structures of the object (4).

11. A method according to claim 1, **characterized in that** mathematical modelling consists of a list or probability distribution of possible attenuation coefficient values in the object (4).

12. A method according to claim 1, **characterized in that** the X-ray imaging geometry, such as X-ray source position, has unknown error modelled in the distribution p(m|x).

13. A method according to claim 1, **characterized in that** the X-radiation measurement noise is Poisson distributed.

14. A method according to claim 1, **characterized in that** the medical X-ray imaging is dental radiography.

15. A method according to claim 1, **characterized in that** the medical X-ray imaging is surgical C-arm imaging.

16. A method according to claim 1, **characterized in that** the medical X-ray imaging is mammography.

17. A method according to claim 1, **characterized in that** three-dimensional information of the object (4) is produced on the basis of the maximum a posteriori estimator (MAP) which is calculated by the equation:

$$p(x_{\mathrm{MAP}} \mid m) = \max p(x \mid m),$$

m representing projection data and x representing the object image vector and where the maximum on the right hand side of the equation is taken over all x.

18. A method according to claim 1, **characterized in that** three-dimensional information of the object (4) is produced on the basis of the conditional mean estimator (CM), which is calculated by the equation:

$$x_{\mathrm{CM}} = \int x\, p(x \mid m)\, dx$$

where m represents projection data and x represents the object image vector.

19. A medical X-ray device (5) arrangement for producing three-dimensional information of an object (4) in a medical X-ray imaging, **characterized in that** the medical X-ray device (5) arrangement comprises:

- means (15) for modelling the object (4) mathematically independently of X-ray imaging
- an X-ray source (2) for X-radiating the object from at least two different directions
- a detector (6) for detecting the X-radiation to form projection data of the object (4)
- and means (15) for utilizing said projection data and said mathematical modelling of the object in Bayesian inversion based on Bayes' formula

$$p(x \mid m) = \frac{p_{pr}(x)p(m \mid x)}{p(m)}$$

to produce three-dimensional information of the object, the prior distribution $p_{pr}(x)$ representing mathematical modelling of the object, x representing the object image vector, which comprises values of the X-ray attenuation coefficient inside the object, m representing projection data, the likelihood distribution $p(m|x)$ representing the X-radiation attenuation model between the object image vector x and projection data m, $p(m)$ being a normalization constant and the posteriori distribution $p(x|m)$ representing the three-dimensional information of the object (4).

20. A medical x-ray device (5) arrangement according to claim 19, **characterized in that** the three-dimensional information of the object (4) is one or more two-dimensional images representing X-ray attenuation coefficient along slices through the object.

21. A medical x-ray device (5) arrangement according to claim 19, **characterized in that** the three-dimensional information of the object (4) is

a three-dimensional voxel representation of the X-ray attenuation in the object.

22. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the measurement as

m = Ax+e,

where matrix A contains the lengths of the path of the X-ray inside each voxel and the noise e is independent of object image vector x leading to the likelihood distribution

$$p(m \mid x) = p_{noise}(m - Ax).$$

23. A medical X-ray device (5) arrangement according to claim 19 **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically so that X-radiation attenuates when passing the object (4), which means that every image voxel is nonnegative.

24. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by the formula:

$$p_{pr}(x) = \exp(-\alpha \sum_{N} U_N(x))$$

where the sum is taken over a collection of 3D neighbourhoods N and the value $U_N(x)$ depends only on the values of voxels belonging to the neighborhood N, and α is a positive regularization parameter used to tune the width of the prior distribution.

25. A medical x-ray device (5) arrangement according to claim 19, **characterized in that** the 3D tomographic problem is divided into a stack

of 2D tomographic problems and on every such 2D problem, and the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by the formula:

$$p_{pr}(x) = \exp(-\alpha \sum_{N} U_N(x))$$

where the sum is taken over a collection of 2D neighbourhoods N and the value $U_N(x)$ depends only on the values of pixels belonging to the neighborhood N, and α is a positive regularization parameter used to tune the width of the prior distribution, and the 2D tomographic problems are related to each other by the formula

pr3D(x(j)) = exp(- γ ΣΣ | x(j)[k,q] - x(j-1)[k,q] |),

where the sums are taken over all pixels (k=1,...,K, q=1,...,Q) and $\gamma > 0$ is another regularization parameter.

26. A medical X-ray device (5) arrangement according to claim 25, **characterized in that** the neighborhood systems consist of two neighboring pixels xj, xk or voxels xj, xk and $U_N(x)$ calculates a power of the

$$p_{pr}(x^{(j)}) = \exp\Big(-\alpha\big(\sum_{k=1}^{K-1}\sum_{q=1}^{Q}|x^{(j)}[k,q]-x^{(j)}[k+1,q]|^s + \\ +\sum_{k=1}^{K}\sum_{q=1}^{Q-1}|x^{(j)}[k,q]-x^{(j)}[k,q+1]|^s\big)\Big)$$

absolute value of the difference, leading to the formula where s is a positive real number and α is a regularization parameter used to tune the width of the prior distribution.

27. A medical X-ray device (5) arrangement according to claim 26, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by setting s=1

corresponding to total variation (TV) prior describing objects consisting of different regions with well-defined boundaries.

28. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by assuming that mathematical modelling is qualitative structural information of the target where the structural information is encoded in prior distributions that are concentrated around image vectors x that correspond to the physiological structures of the target.

29. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by assuming that mathematical modelling consists of a list of possible attenuation coefficient values in the object.

30. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by assuming that the X-ray imaging geometry, such as X-ray source position, has unknown error modelled in the distribution $p(m|x)$.

31. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for modelling the object (4) mathematically by assuming that X-radiation measurement noise is Poisson distributed.

32. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray imaging is dental radiography.

33. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray imaging is surgical C-arm imaging.

34. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray imaging is mammography.

35. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for producing three-dimensional information of the object (4) on the basis of the maximum a posteriori estimator (MAP), which is calculated by the equation:

$$p(x_{\mathrm{MAP}} \mid m) = \max p(x \mid m),$$

m representing projection data and x representing the object image vector and where the maximum on the right hand side of the equation is taken over all x.

36. A medical X-ray device (5) arrangement according to claim 19, **characterized in that** the medical X-ray device arrangement comprises means (15) for producing three-dimensional information of the object (4) on the basis of the conditional mean estimator (CM), which is calculated by the equation

$$x_{\mathrm{CM}} = \int x\, p(x \mid m)\, dx$$

where m represents projection data and x represents the object image vector.